Overview of Passive Satellite Cloud Retrievals and Methods:

ACE

vs. ACE vs. ACOB

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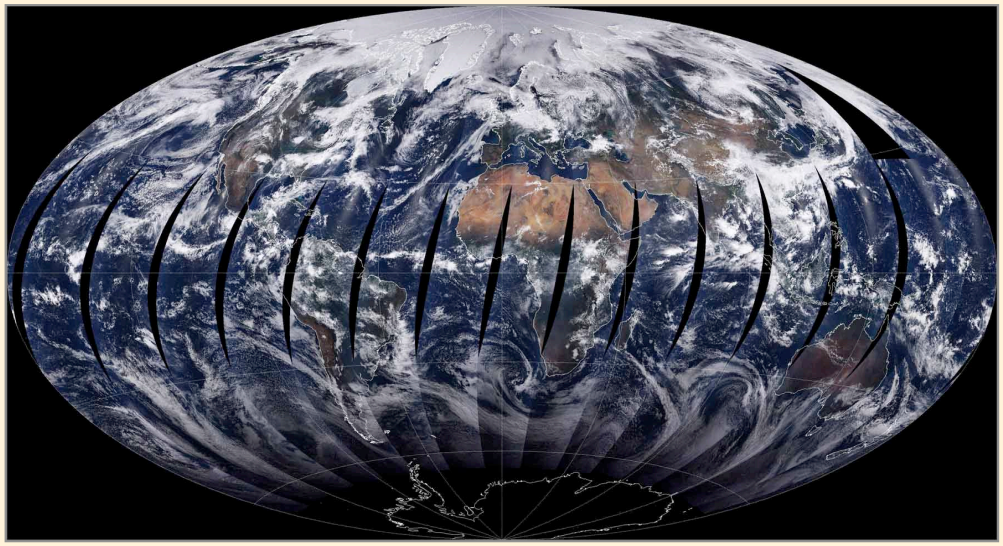
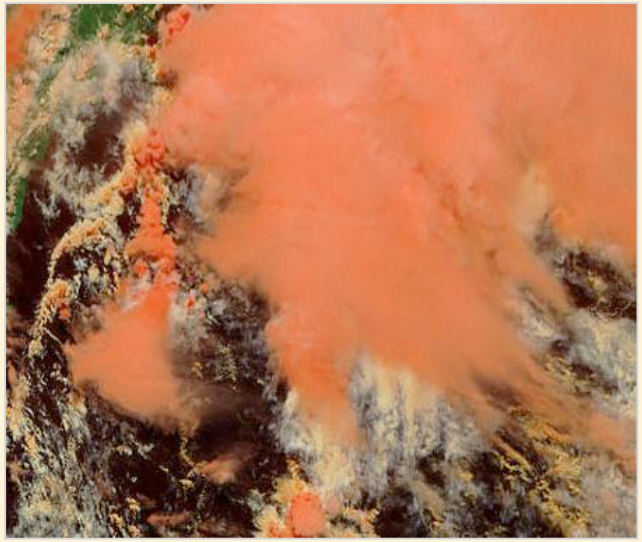




Topics

- Why clouds? What properties?
- Retrieval approaches (non-polarimetric)
  - Spectral information and existing satellite imagers
- Retrieval issues and uncertainties
  - Examples from MODIS, POLDER, microwave radiometers, …
- Gaps in current capabilities and ACE: *discussion*

Why Cloud Observations?

There are a number of fundamental reasons …

- Establish climate quality data records of relevant cloud properties ("Systematic Observations")
  - Quantify trends, assist in quantifying cloud feedbacks
  - Radiation budget (e.g., CERES/MODIS/GEO)
  - Water budget/cycle (e.g., role of ice clouds and convection in UTH)
- Cloud process studies, including aerosol-cloud interactions
  - Effect of clouds on other processes, e.g., effect on photochemistry (*Liu et al.*, 2006, 2008), ocean biological processes, …
- MODEL development
  - climate model validation
  - aid to development of physically-based cloud schemes and parameterizations
  - forecast model assimilation (*Benedetti and Janiskova*, 2008)

Cloud Products and Techniques

- **Cloud detection/masking**
  - Multispectral and/or multiview imagers with appropriate spatial resolution, lidar, radar
- **Cloud thermodynamic phase**
  - Multispectral imagers w/SWIR and/or IR (8.5 μm) bands, polarimeters w/multiangular views and good spatial resolution, lidars w/depolarizaton capability
- **Cloud top properties**: pressure, temperature, effective emissivity
  - Multispectral and/or multiview imagers (thermal window, CO_2 bands, other gas absorbing bands), UV imagers, polarimeters
- **Cloud optical & microphysical properties:** optical thickness, τ, effective particle size, r_e, water path
  - Solar reflectance imagers (r_e from 1.6, 2.1, 3.7 μm bands)
  - IR imager and hyperspectral retrievals of τ, r_e for thin clouds
  - Polarimeter w/multiangular views (r_e)
  - Microwave radiometers (water path)

The Afternoon Constellation (A-Train)

Matrix of Operational/Standard Level-2 (pixel-level) Cloud Products

		MODIS	AIRS	POLDER	AMSR-E	CloudSat	CALIPSO
macro-physical	cloud detection	X		X		X[1]	X
	cloud height/pressure	X	X	X			
	multilayer info	X					
optical/micro	cloud phase	X					
	τ	X					
	r_e	X		X		X[2]	
mass	IWP	X				X	
	LWP	X			X	X[2]	
	flux/heating rates					X[2]	
		1 km	13	6	~20	0.5, 2.5	~ 0.06, 1 (avg. of 3 shots for BL cloud)
		2D structure: horizontal				vertical, horizontal	

All are relevant to process studies involving the consequences of aerosols on clouds and precip.

[1] w/CALIOP

[2] w/MODIS

Some Issues (Gaps) in Passive Retrievals

- Instrument characterization (radiometric calibration, etc.)
- Retrieval issues
  - Cloud detection: detection limits (cirrus), false detection from heavy smoke and dust, sun glint, snow/ice surfaces; detection that is a function of spatial resolution ("not clear" detection); sufficient heterogeneity for multiview detection
  - Cloud thermodynamic phase
  - Ice cloud models
  - Thin cirrus retrievals
  - Multilayer/multiphase scenes: detectable? correctable? Impact on retrievals (cloud-top and optical properties)?
  - Boundary conditions: surface spectral albedo (VNIR/SWIR), IR spectral emissivity and surface skin temperature, μwave emissivity, snow/ice extent
  - Vertical inhomogeneity: retrieved r_e varies with $r_e(\tau)$ and retrieval wavelength
  - Partly cloudy pixels and general 3D cloud effects
  - Provide retrieval uncertainties (for at least a subset of error sources)

Passive Retrieval Issue Examples:
Cloud Detection & Height Validation

What is a cloud?

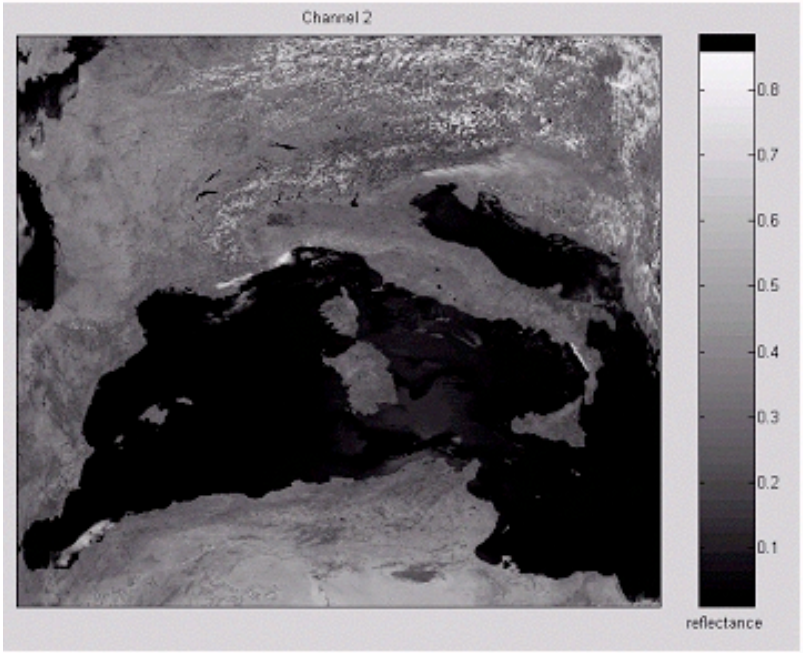
An ill-defined quantity.

From the perspective of remote sensing, the application and the instrument determine the answer. What is considered a cloud in one application may be defined as clear in another ...

… this seems obvious but we will argue about this later!

Some tests see cloud …

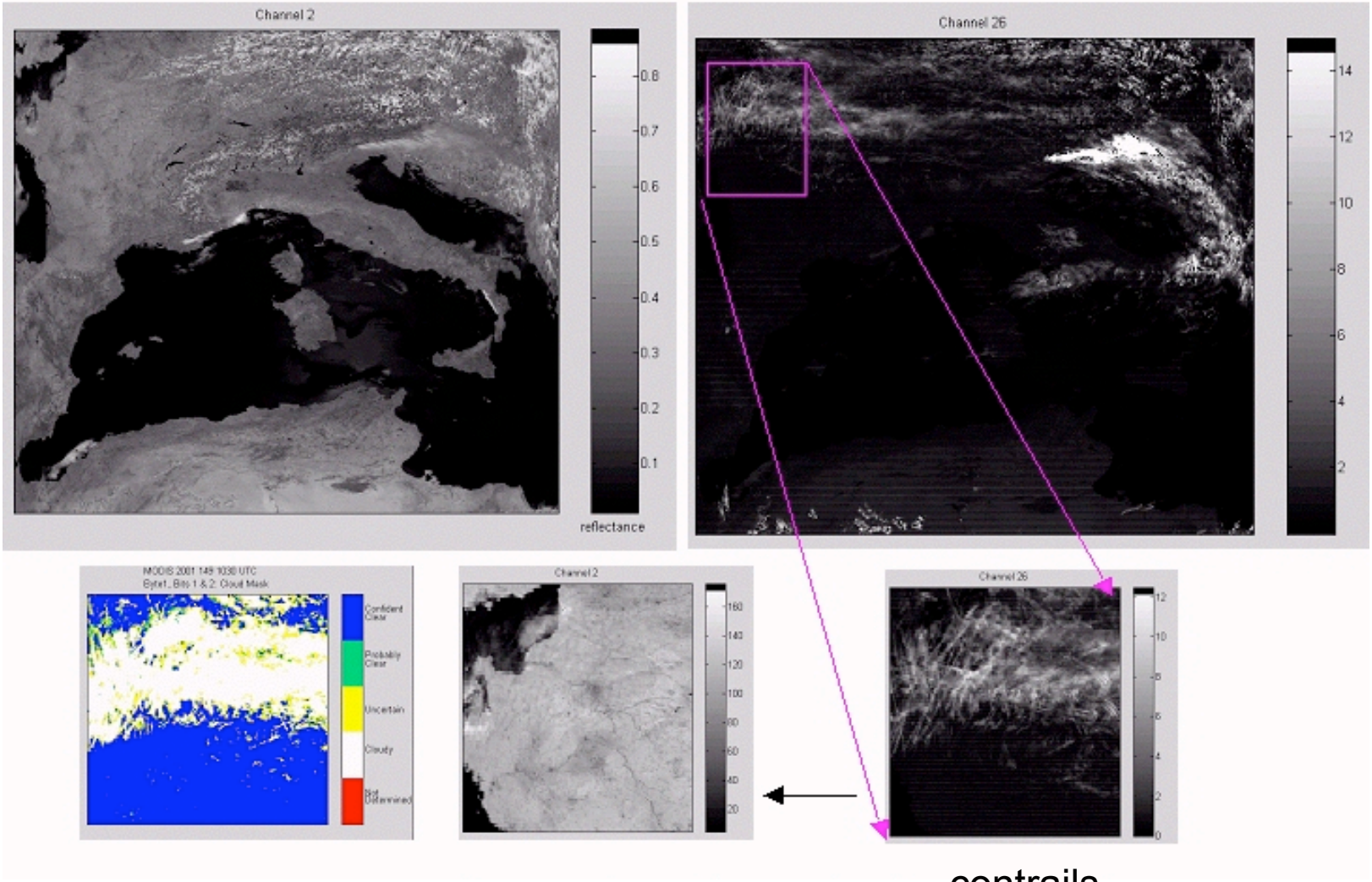
MODIS b2, 0.86 μm



Some tests see cloud, some don't

MODIS b2, 0.86 µm

MODIS b26, 1.38 µm



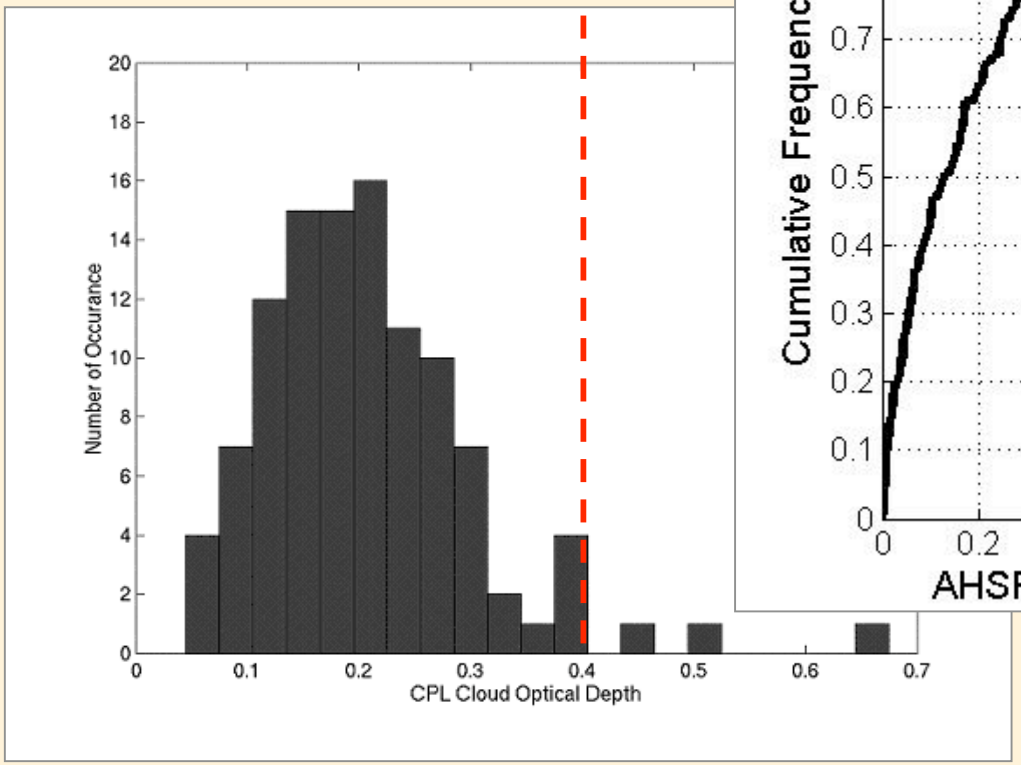
contrails

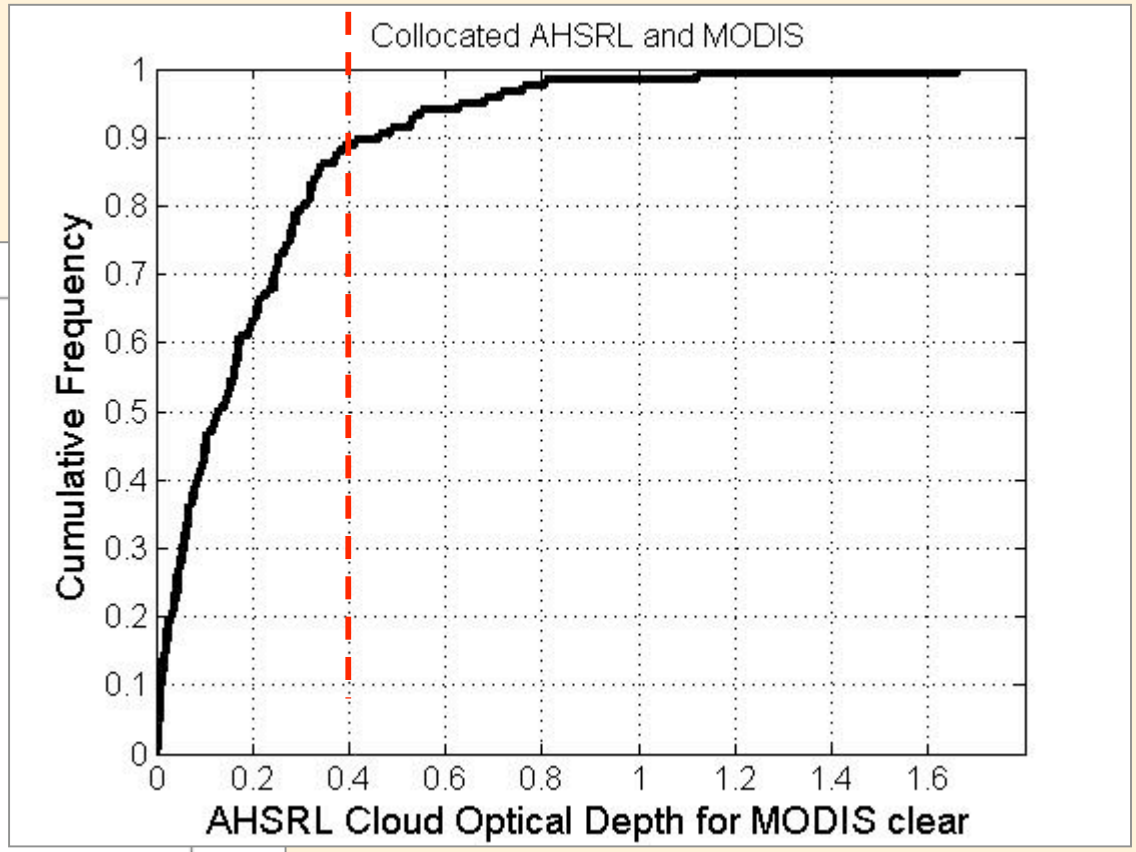
Passive Retrieval Issue Examples: Cloud Detection & Height Validation

Lidar τ distribution when lidar says “cloudy”, passive says “clear”

When disagreement occurs, detection limit τ ~0.4

CPL, McGill, CRYSTAL-FACE



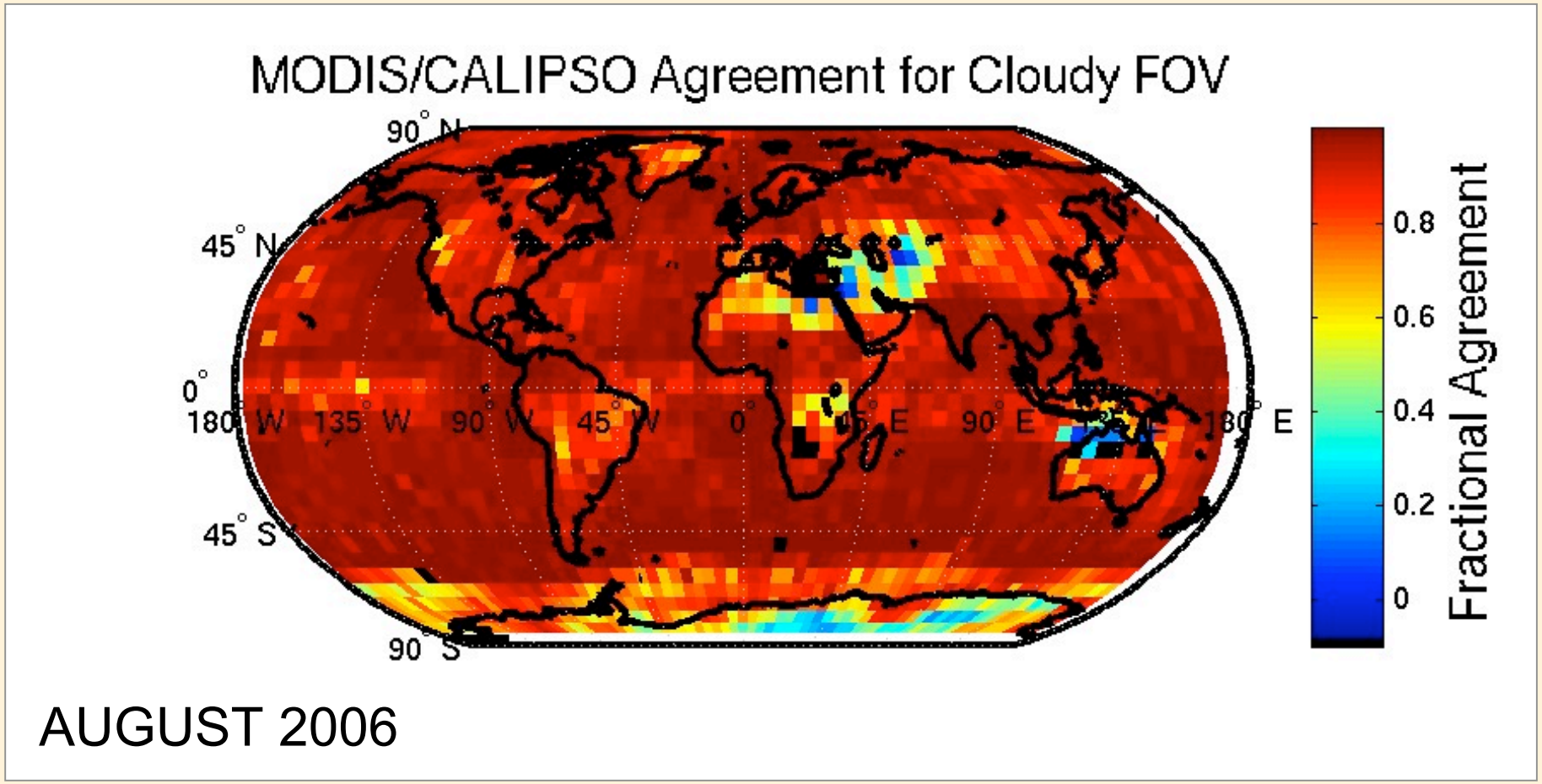


AHSRL, Ed Eloranta, Madison site

(Ackerman et al., 2008)

The fractional agreement between the MODIS and CALIOP cloud mask for cloudy FOV. The fraction agreement calculated at 5-degree resolution.

(Holz et al., 2008)



AUGUST 2006

Passive Retrieval Issue Examples:
Cloud Detection & Height Validation

What is meant by Cloud Height?

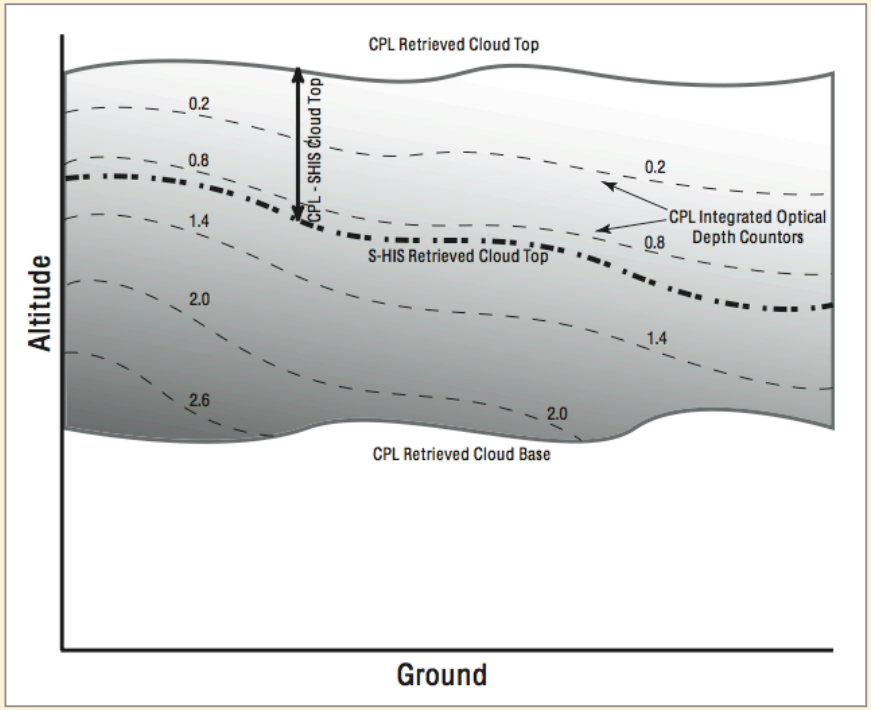
Another ill-defined quantity.

From the perspective of remote sensing, the application and the instrument determine the answer …

... but, we understand the physics and the issues!

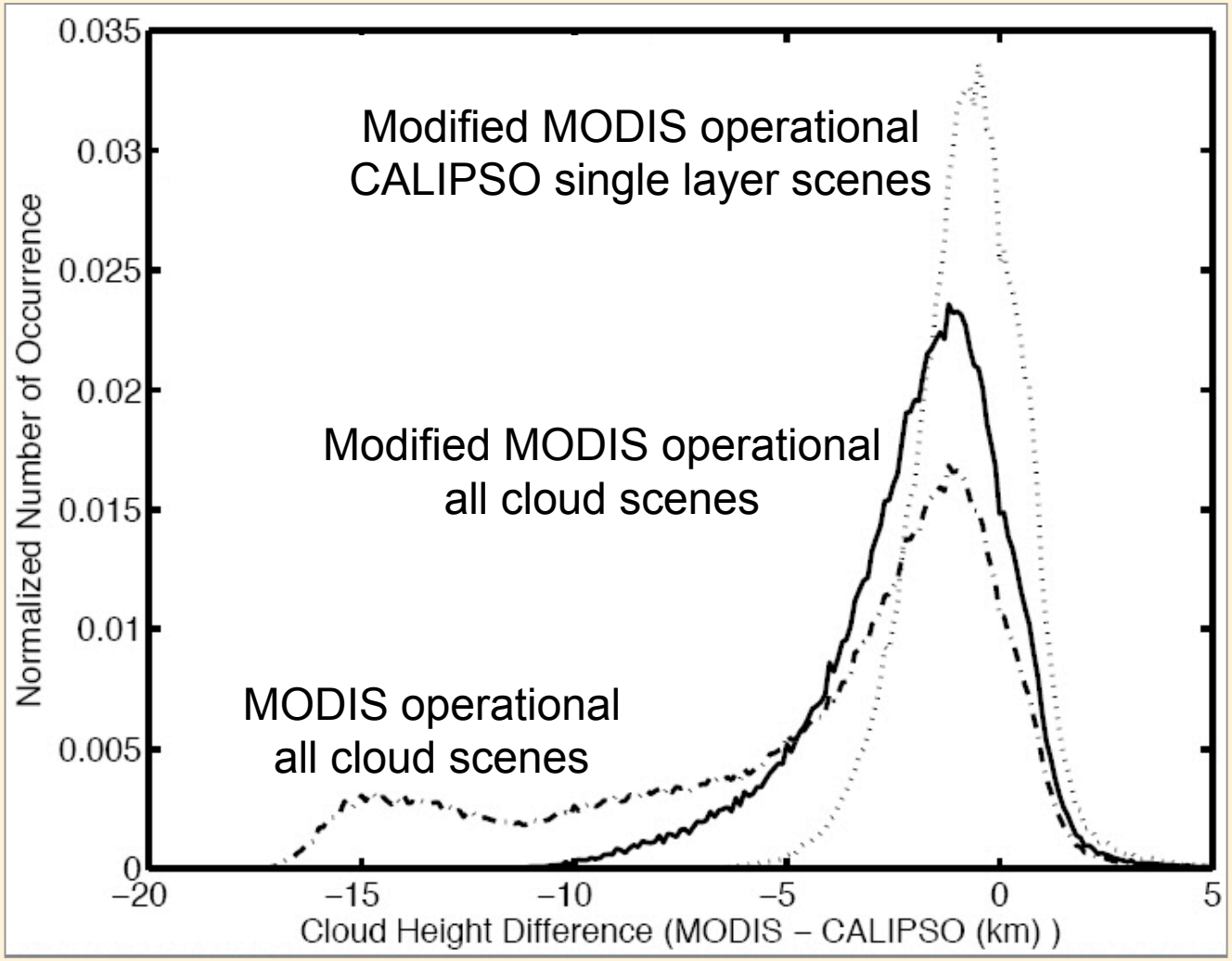
Passive Retrieval Issue Examples: Cloud Detection & Height Validation

we understand what IR retrieved “cloud top” means



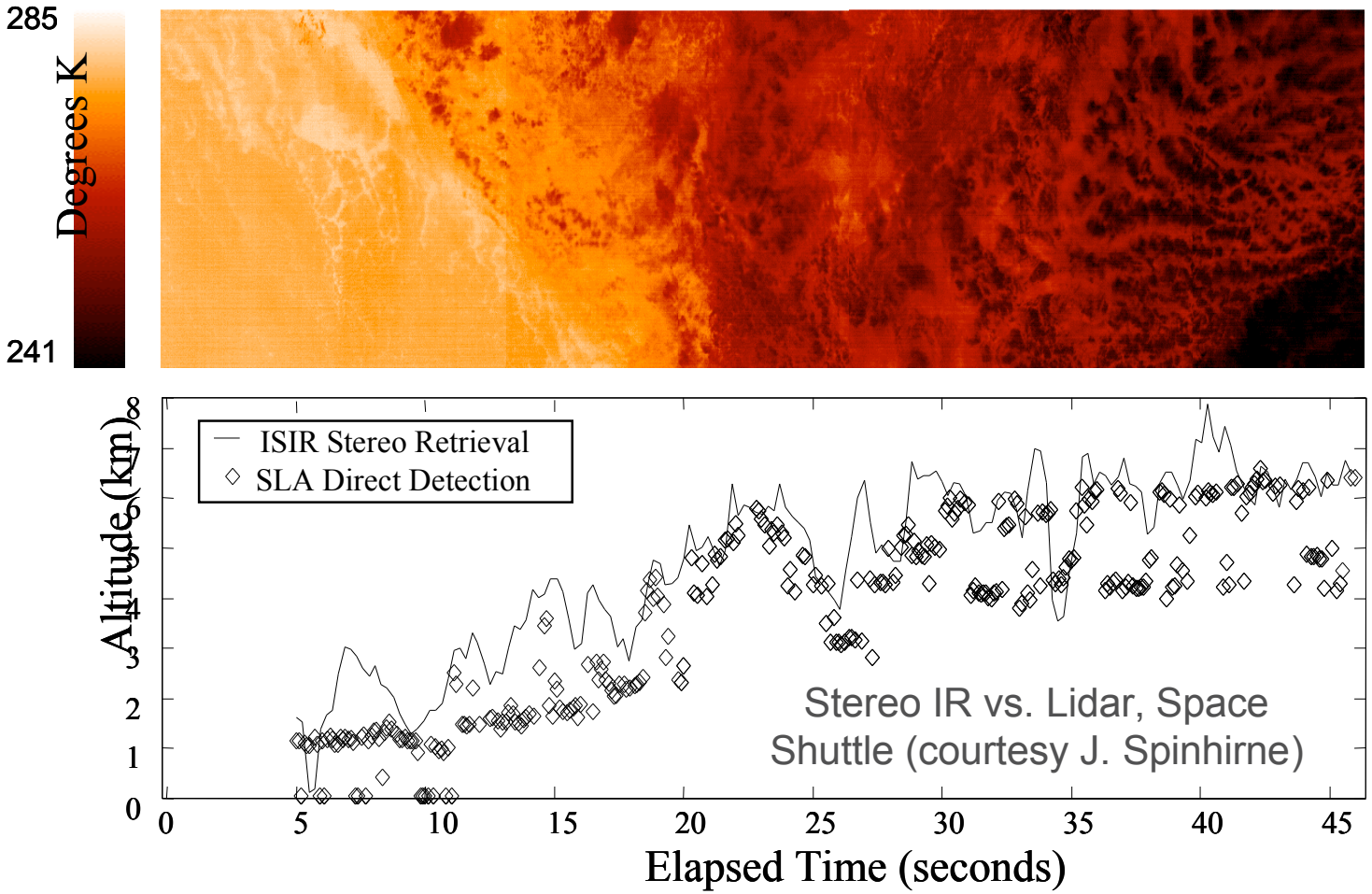
A schematic of the lidar integrated cloud optical depth at the level of the passive IR cloud top retrieval (Holz et al., 2006).

Passive Retrieval Issue Examples: Cloud Detection & Height Validation (Holz et al., 2008)



Passive Retrieval Issue Examples: Cloud Detection & Height Validation

we CAN understand IR stereo retrieved “cloud top”

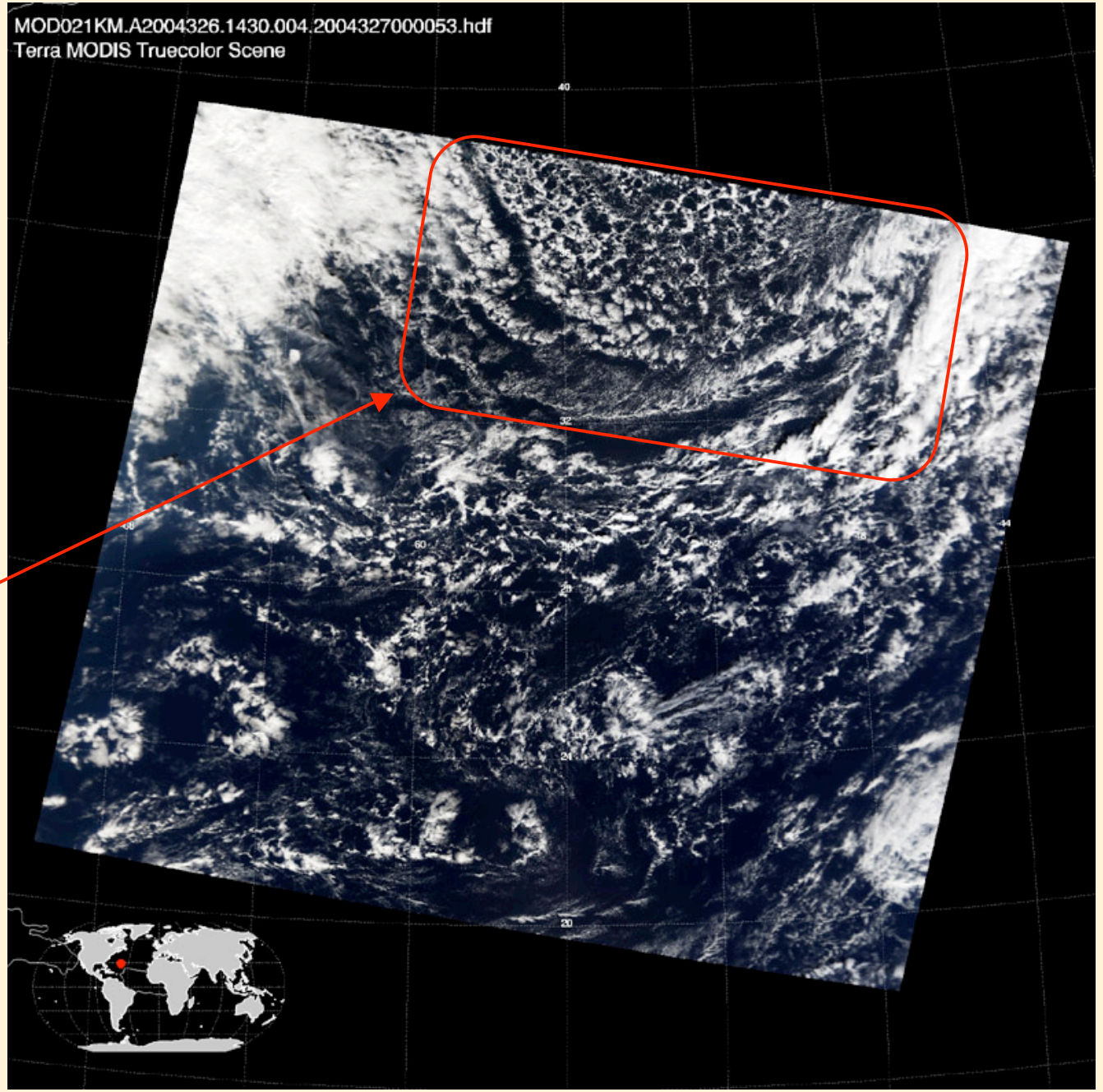


Passive Retrieval Issue Examples

- Cloud thermodynamic phase
  - Passive difficulties in inferring clouds with “supercooled” temperatures. If ACE wants microphysics, then ACE requires phase. Need more spectral information in the 1.6 and 2.1 μm bands for phase detection (Pilewskie and Twomey, 1987)
  - Mixed phase detection including quantitative mixed phase optical properties
- 3D effects, including quantitative retrievals of broken/non-stratiform boundary layer clouds (important cloud type for aerosol-cloud interactions)
  - Trade Cu, broken (open cell) Sc: partly cloudy imager retrievals with some assumptions (Coakley et al.)
  - Boundary layer clouds over land
  - Detection and quantification of drizzle in these clouds: information in imager r_e retrievals, microwave radiometers, radars with sufficient sensitivity/ranging?

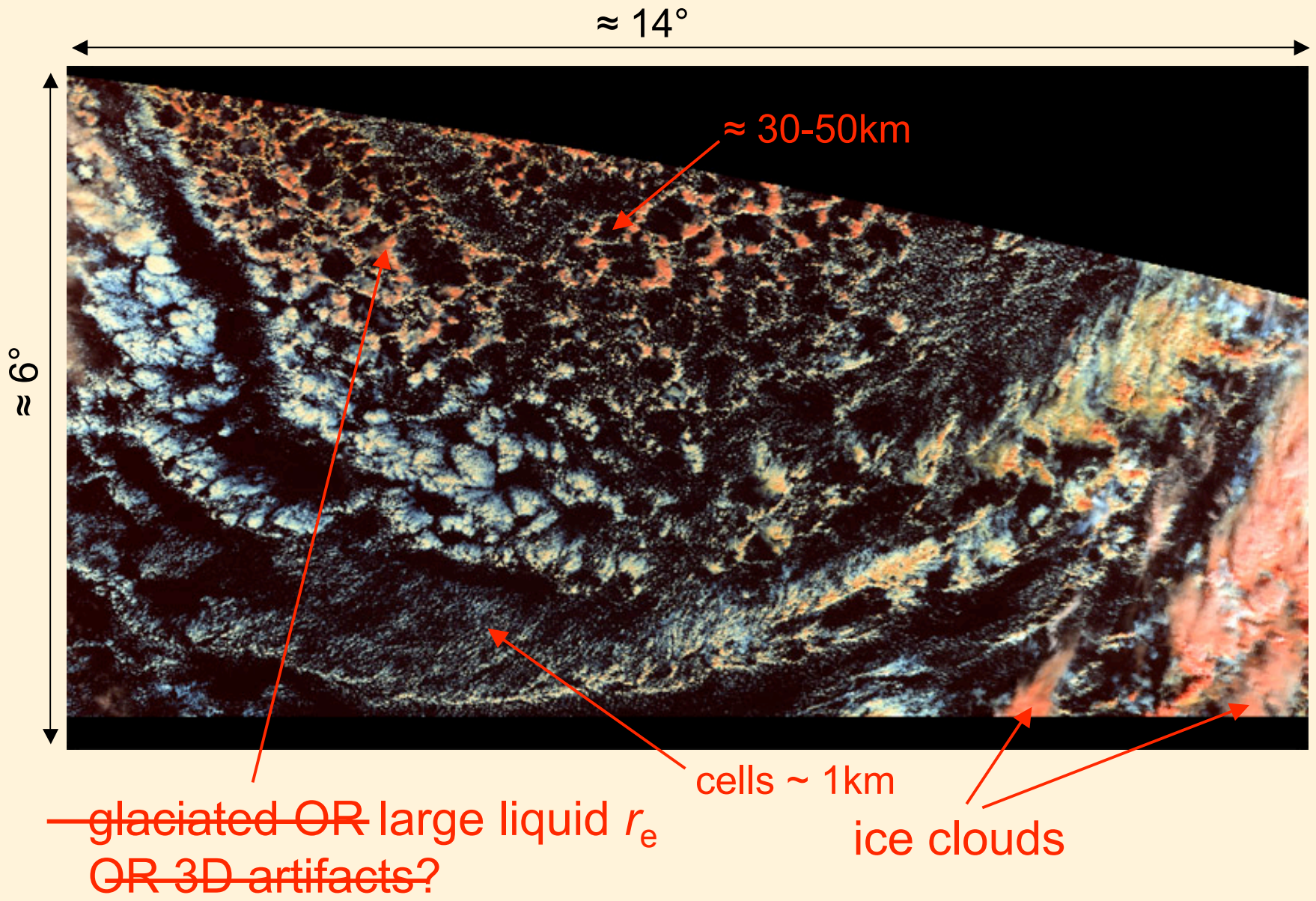
21 Nov 2004
MODIS Terra
1430 UTC
True Color Composite

a closer look …



21 Nov 2004, MODIS Terra, 1430 UTC

SWIR Composite (RGB = 0.65, 1.6, 2.1 μm)



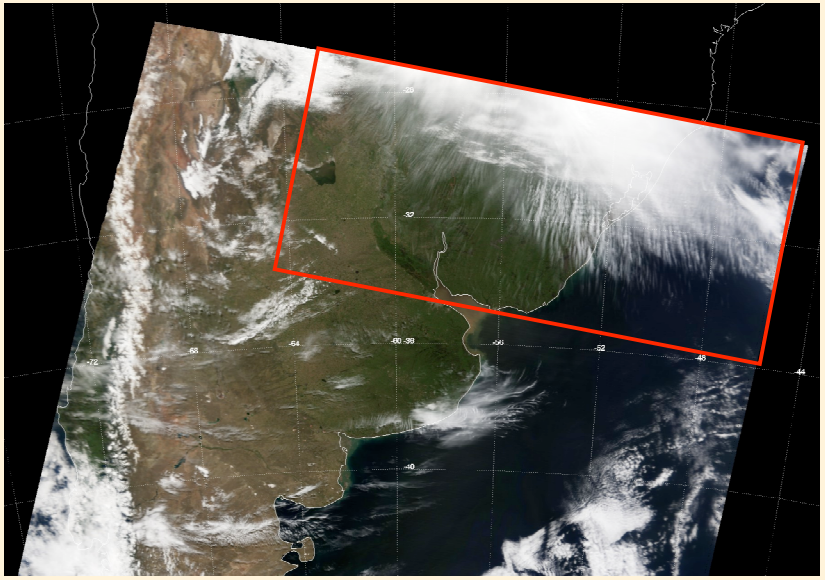
Passive Retrieval Issue Examples, cont.

- Ice cloud models
  - Also relevant to multiple scattering effects in lidar cirrus extinction retrievals (energy in the forward peak of the phase function)
  - Tropical, midlatitude, polar models? Correlations to synoptic (dynamic/thermodynamic) history?
- Ice cloud mass: passive submillimeter imagers for ice water path (to complement microwave liquid water path) are not yet available
- Thin cirrus retrievals
  - Small signal, dependence of surface spectral reflectance

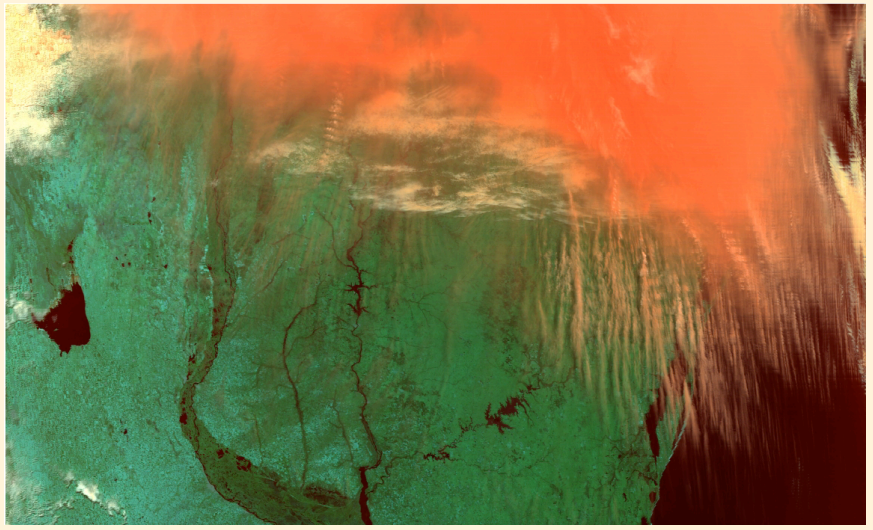
Passive Retrieval Issue Examples: Thin Cirrus, 1.38 μm

(K. Meyer, S. Platnick)

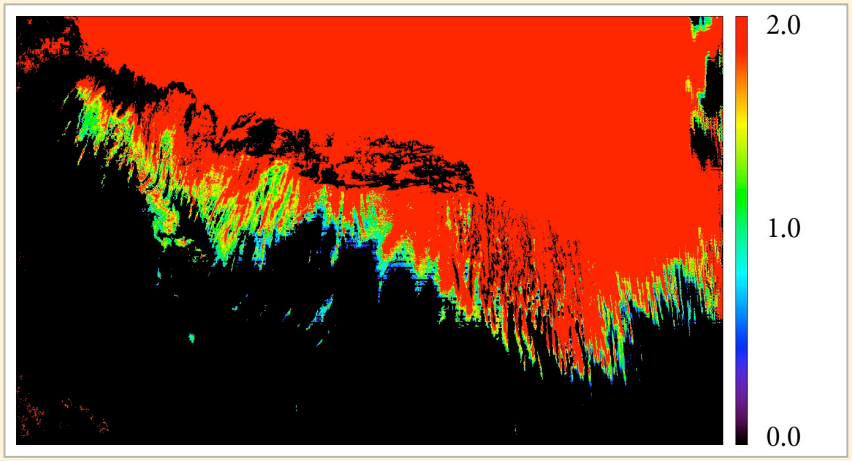
Terra MODIS: 10-21-2007



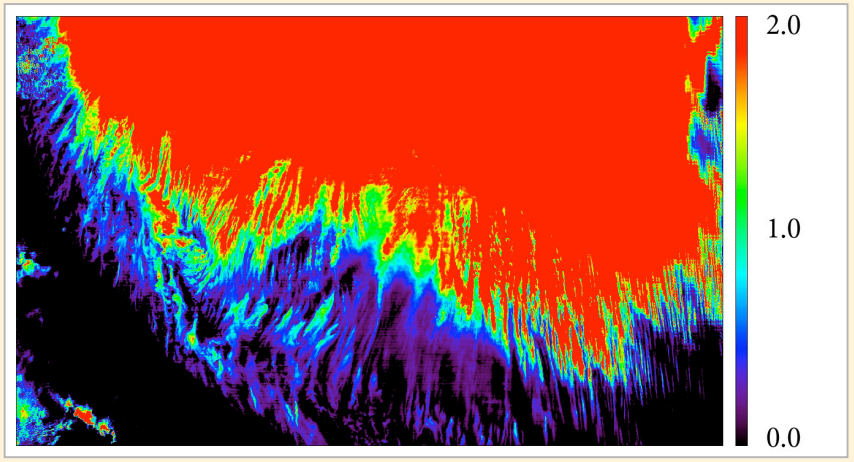
RGB (0.47-, 1.64-, 2.11-μm))



MOD06 Ice Cloud Optical Thickness

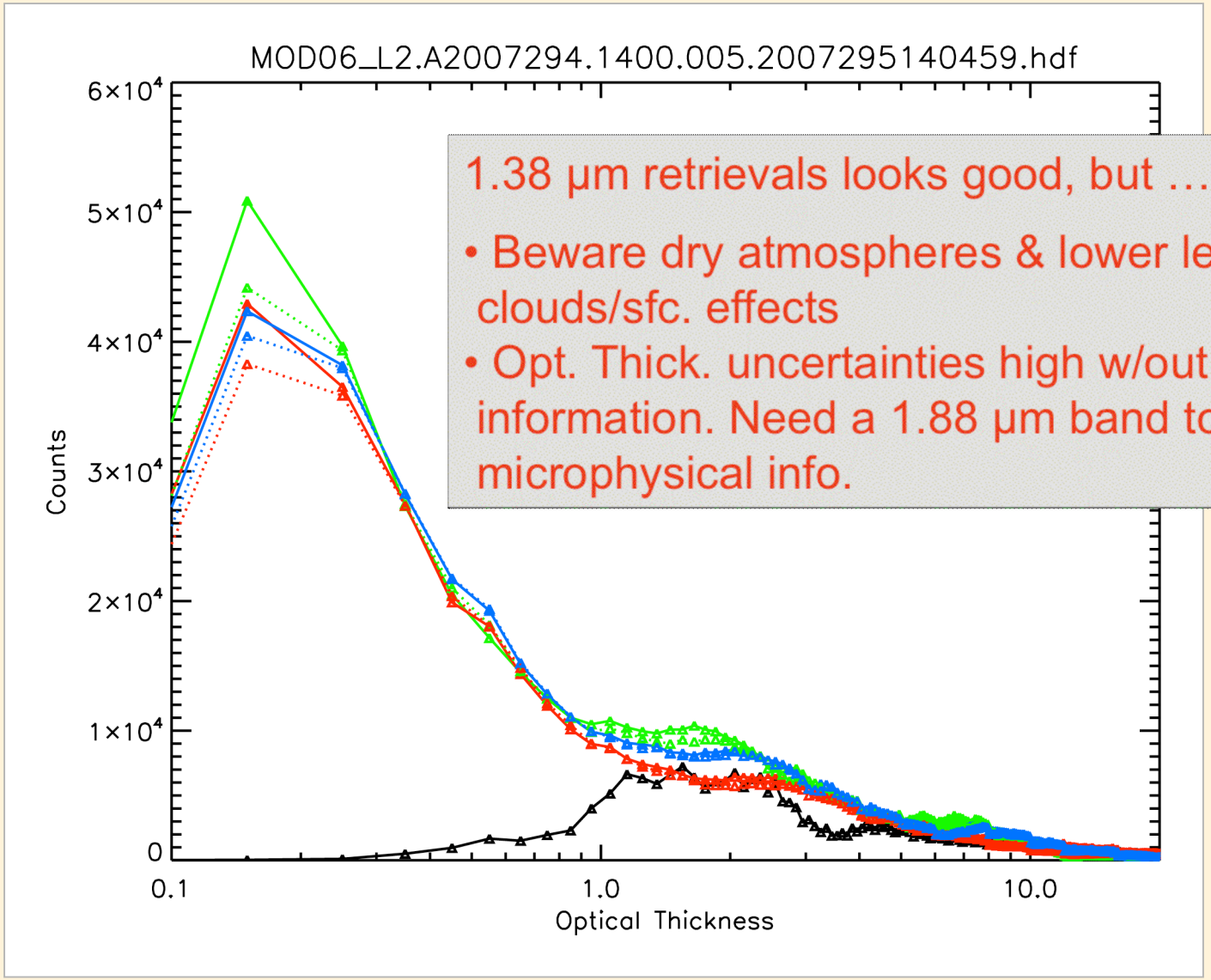


Ice Cloud Optical Thickness
Empirical: Corrected 1.38-μm Reflectance



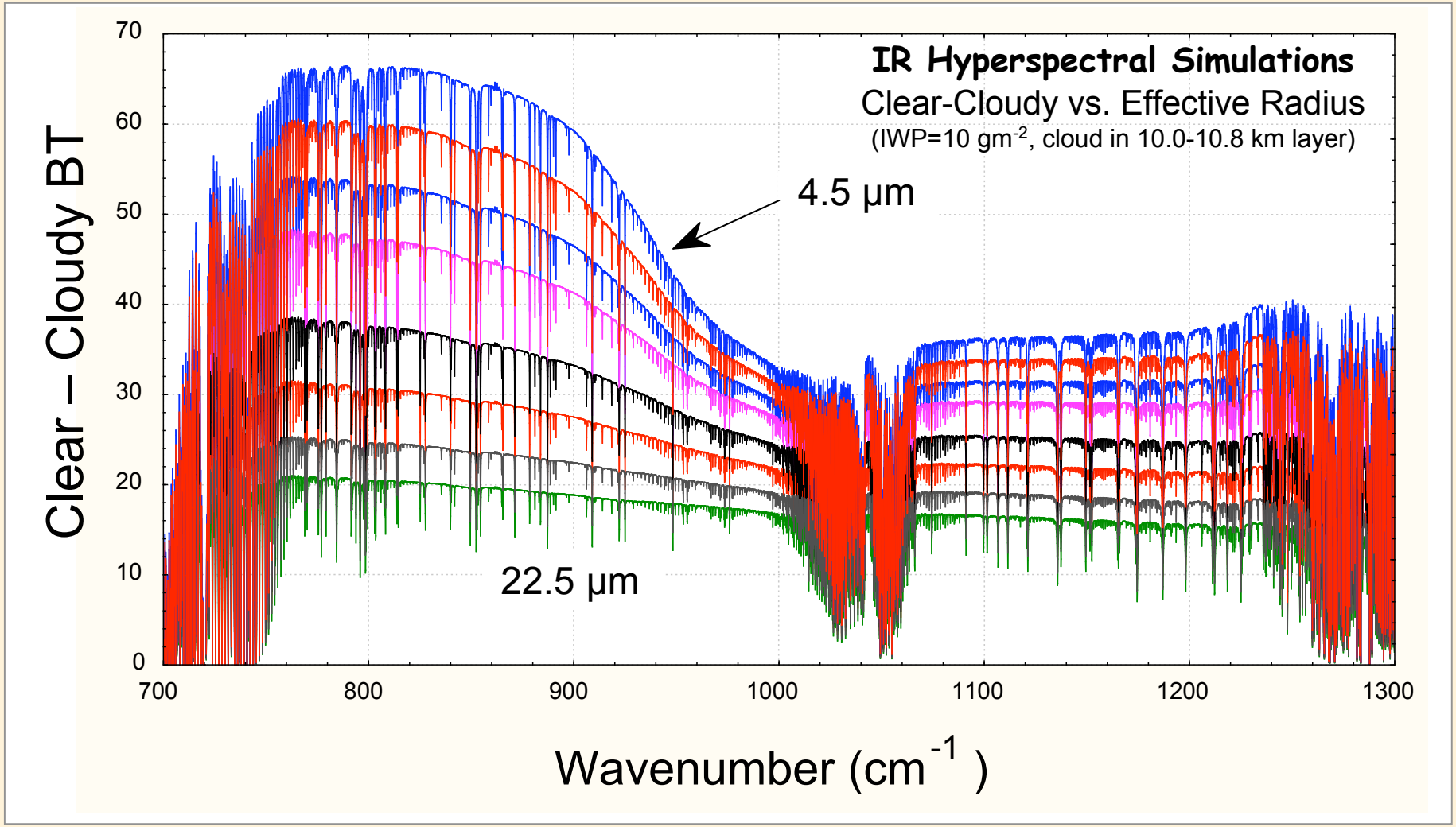
Passive Retrieval Issue Examples: Thin Cirrus, 1.38 µm

(K. Meyer, S. Platnick)



Passive Retrieval Issue Examples: Thin Cirrus, IR Methods

… we understand the issues involved in IR retrievals



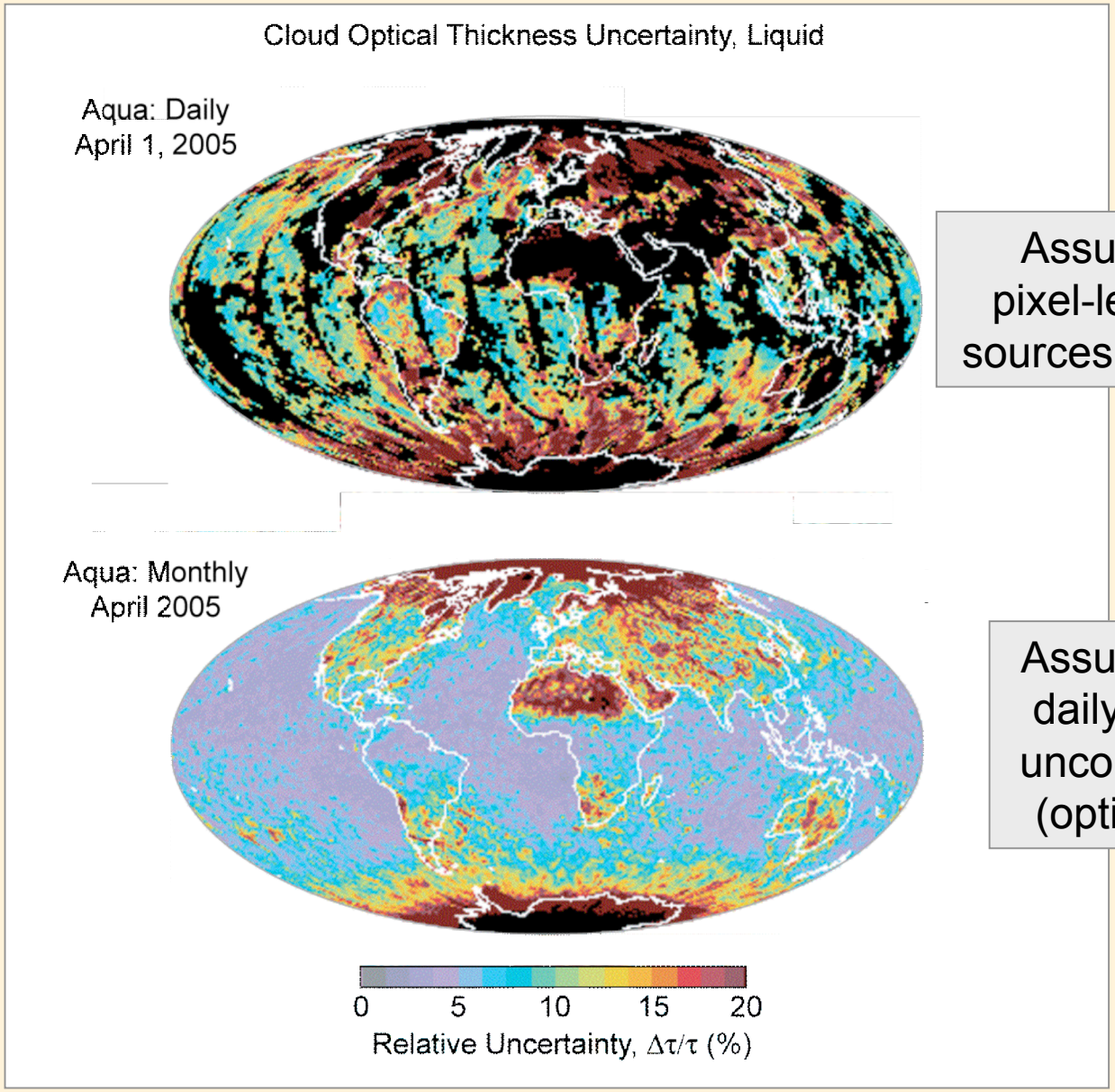
IR is sensitive to smaller particle modes

Passive Retrieval Issue Examples, cont.

- Ice cloud models
  - Also relevant to multiple scattering effects in lidar cirrus extinction retrievals (energy in the forward peak of the phase function)
  - Tropical, midlatitude, polar models? Correlations to synoptic (dynamic/thermodynamic) history?
- Ice cloud mass: passive submillimeter imagers for ice water path (to complement microwave liquid water path) are not yet available
- Thin cirrus retrievals
  - Small signal, dependence of surface spectral reflectance
- Uncertainties?
  - MOD06 provides “baseline” uncertainties for τ, r_e, and *WP*

Uncertainty in Mean τ : Daily & Monthly Example

liquid water clouds, MODIS Aqua C5



Assumption: pixel-level error sources correlated

Assumption: daily errors uncorrelated (optimistic)

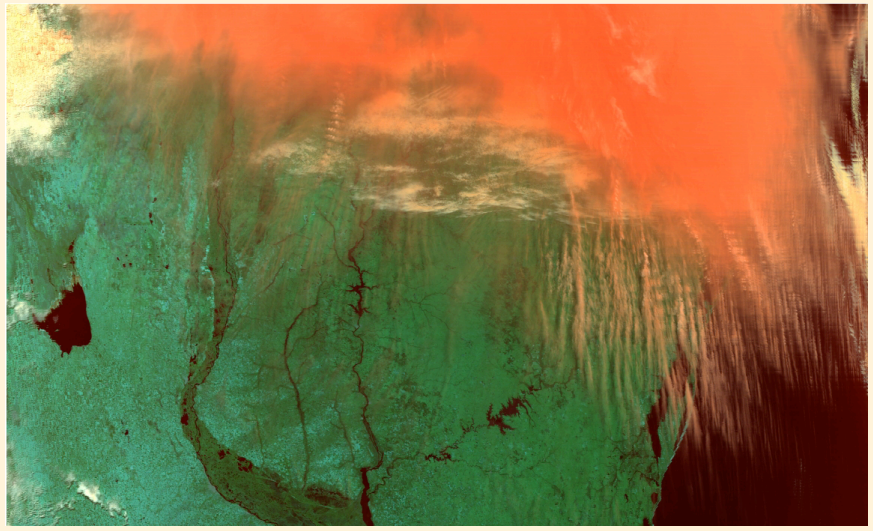
Passive Retrieval Issue Examples, cont.

And of particular importance for aerosol-cloud interactions …

- Cloud dynamics/thermodynamics!
  - Convective updraft velocities: fundamentally effects S_{max} and size distribution
  - Entrainment and mixing processes
  - Thermodynamic fields
  - Temporal evolution

… imagers provide meteorological context for process studies

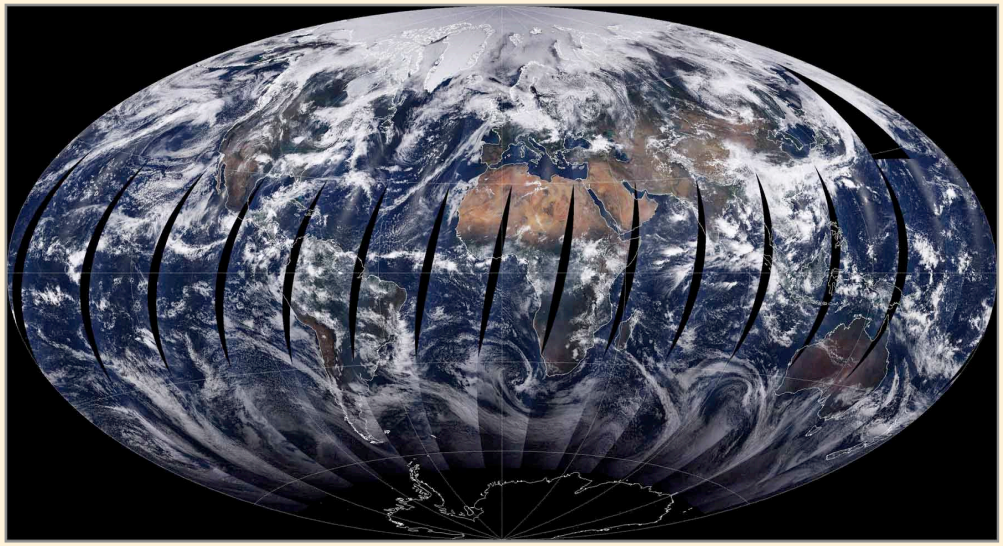
RGB (0.47–, 1.64–, 2.11–μm))

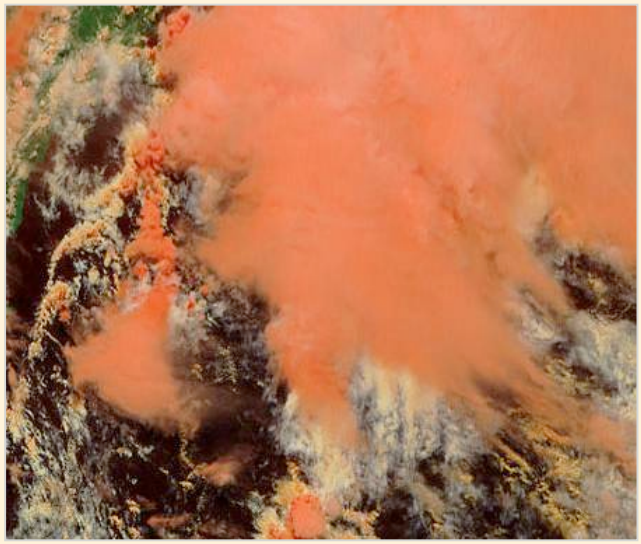


Discussion/Recommendations w.r.t. Cloud Imager

We have the experience and understanding of imager capabilities to assess the impact of mission science goals on instrument characteristics.

If we know the science requirements – we'll tell you what the passive solar/IR imager can contribute and the associated instrument specs.





Discussion/Recommendations w.r.t. Cloud Imager

- Cloud-aerosol interactions occur across the gamut of spatial/temporal scales, are complex, and require a full understanding of cloud properties (in addition to aerosol and dynamic/thermodynamic properties, model analysis, ancillary data, etc.).
- Capabilities of An ACE imager should include …
  - MODIS-like cloud retrievals => inclusion of SWIR, CO_2, and water vapor bands. Bonus: bridge a partial cloud systematic observation gap not anticipated/addressed by DS.
  - Additional spectral coverage for thermodynamic phase detection (can't do microphysical retrievals w/out knowledge of phase)
  - Capable of providing synergy for fused active/passive/polarimetry cloud retrievals
  - Provide swath coverage to provide meteorological context for active sensors